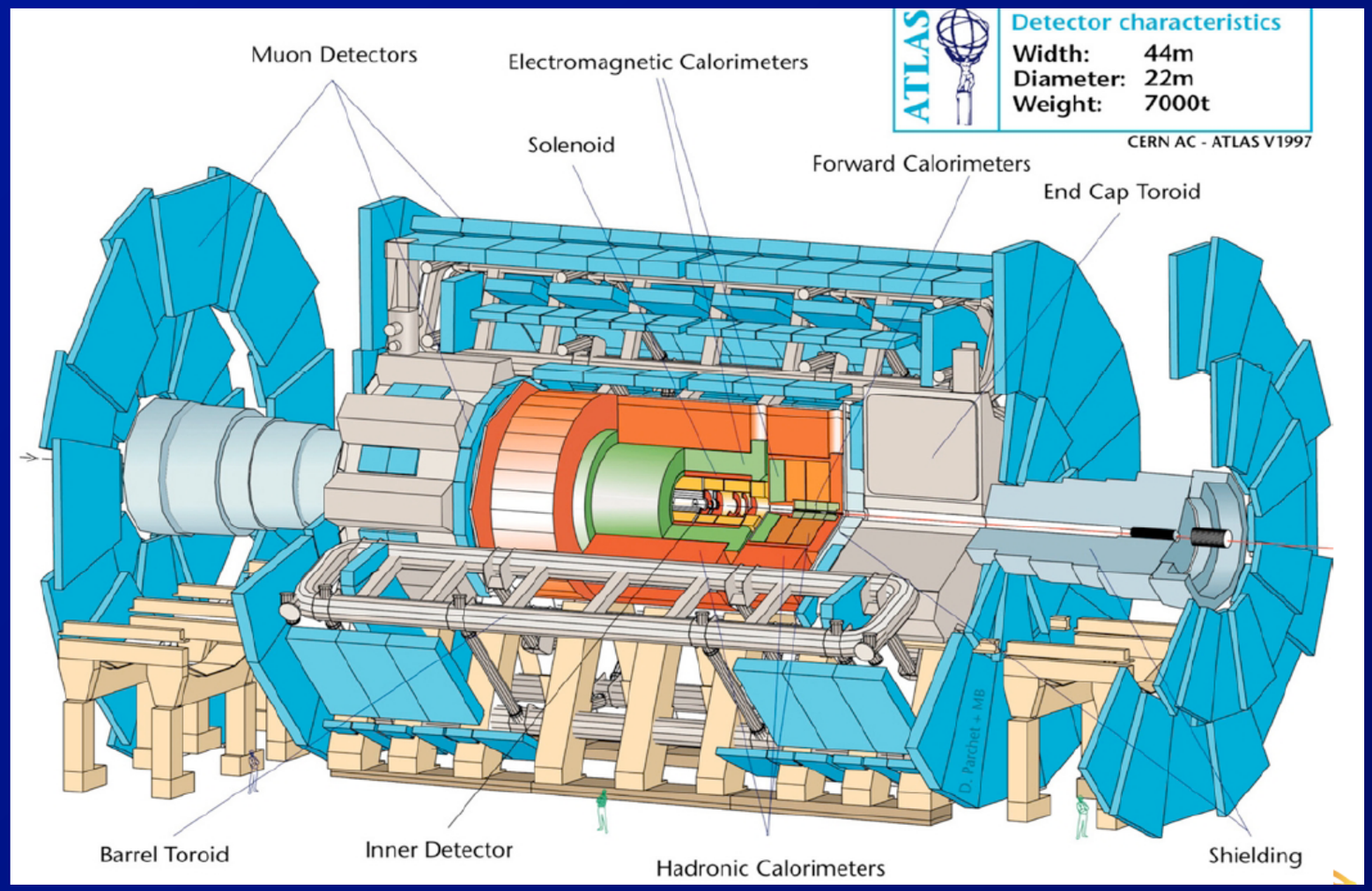
Low-x Measurements with ATLAS

Brian A. Cole, Columbia University

May 12, 2010



Some ancient history

p-A Physics in ATLAS - Overview

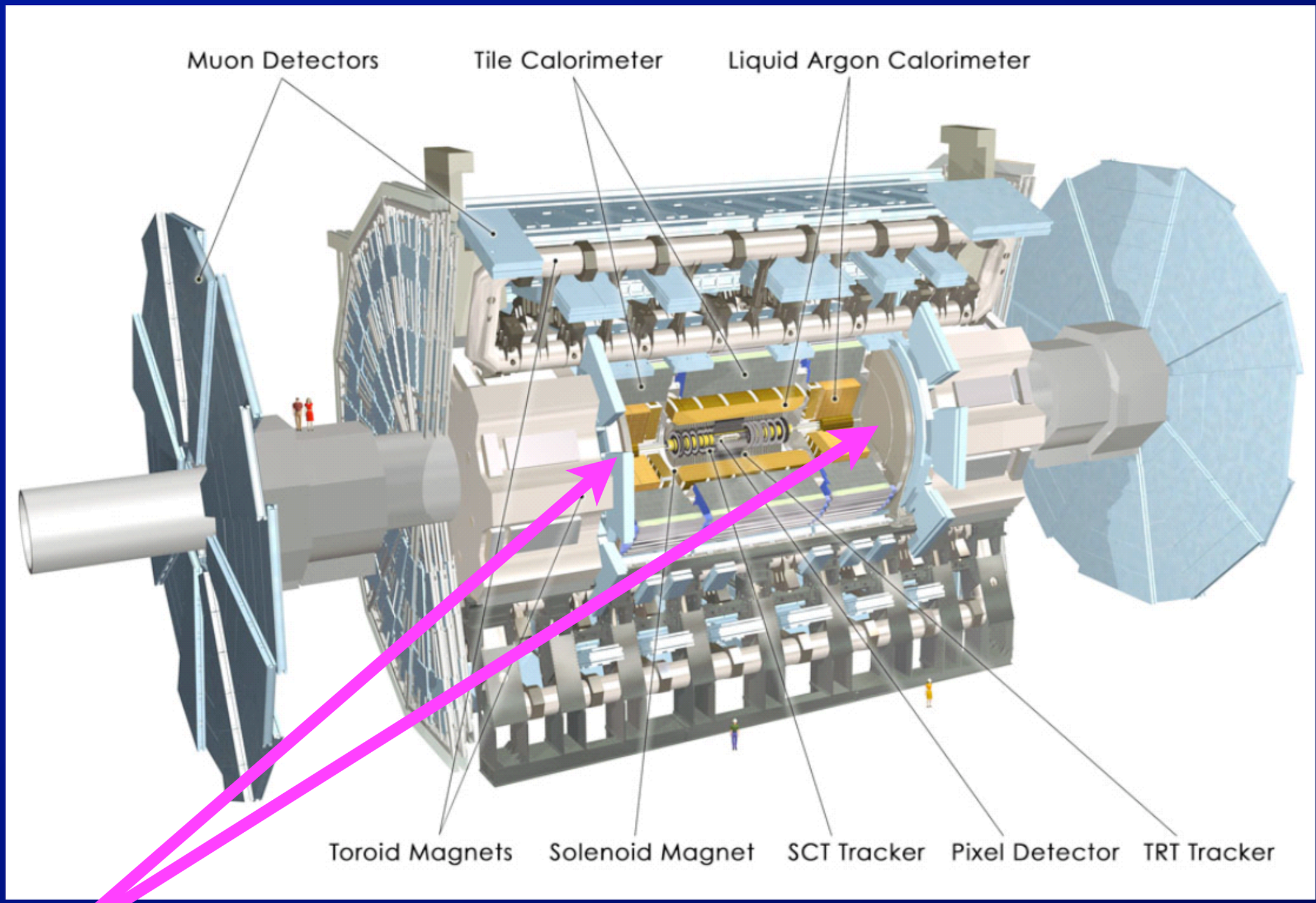
- Study of p-A collisions is essential @ LHC
  - To provide baseline for heavy ion measurements.
  - Physics intrinsically compelling
    - Mini-jet production, multiple semi-hard scattering.
    - Shadowing – test of "Eikonal" QCD.
    - Gluon saturation – probe QCD @ high gluon density.
    - Test factorization.
    - Multiple hard scattering – Measure parton correlations in nucleon (and nucleus ?)
- ATLAS is ideal detector for p-A studies
  - η coverage, calorimeter performance, b tagging, lepton identification, inner tracking.

- **Low-x physics was the reason I became interested in ATLAS in the first place …**

“Low-x” Measurements in ATLAS

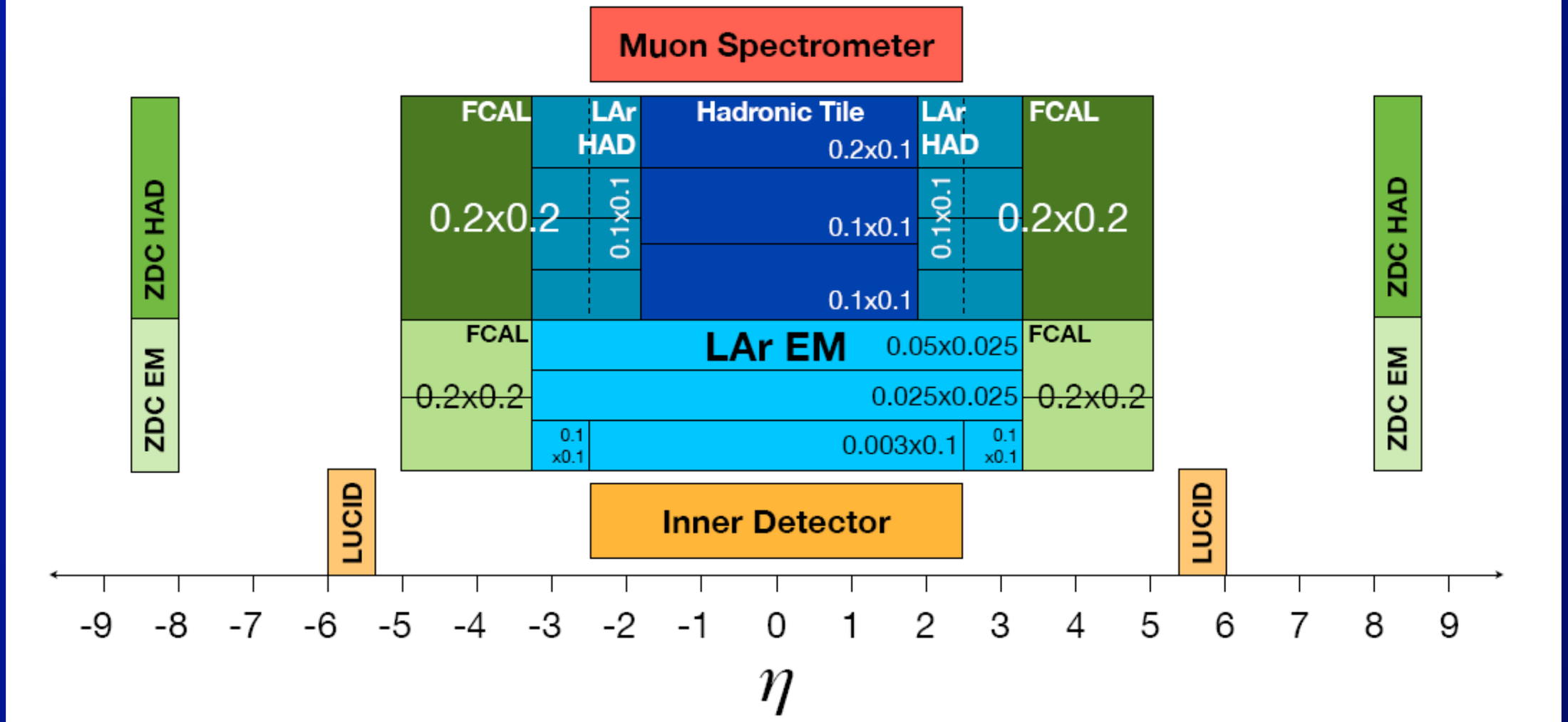
- **p+p**
  - Inclusive particle production
  - Rapidity-separated jets (BFKL)
  - Diffractive hard processes (BFKL)
- **Pb+Pb**
  - Inclusive particle production
  - Direct photon, Z production (shadowing)
    ⇒Measure b dependence of shadowing?
  - Ultra-peripheral (γ^*+A)
- **p+Pb**
  - ~ all hard processes especially γ+jet (shadowing)
  - Moderate p_T hadrons, jets, direct γ vs η
  - Very forward π^0 production with ZDC with fully implemented high-resolution EM module

The ATLAS Detector: Schematic



MBTS
trigger scintillators

ATLAS Acceptance



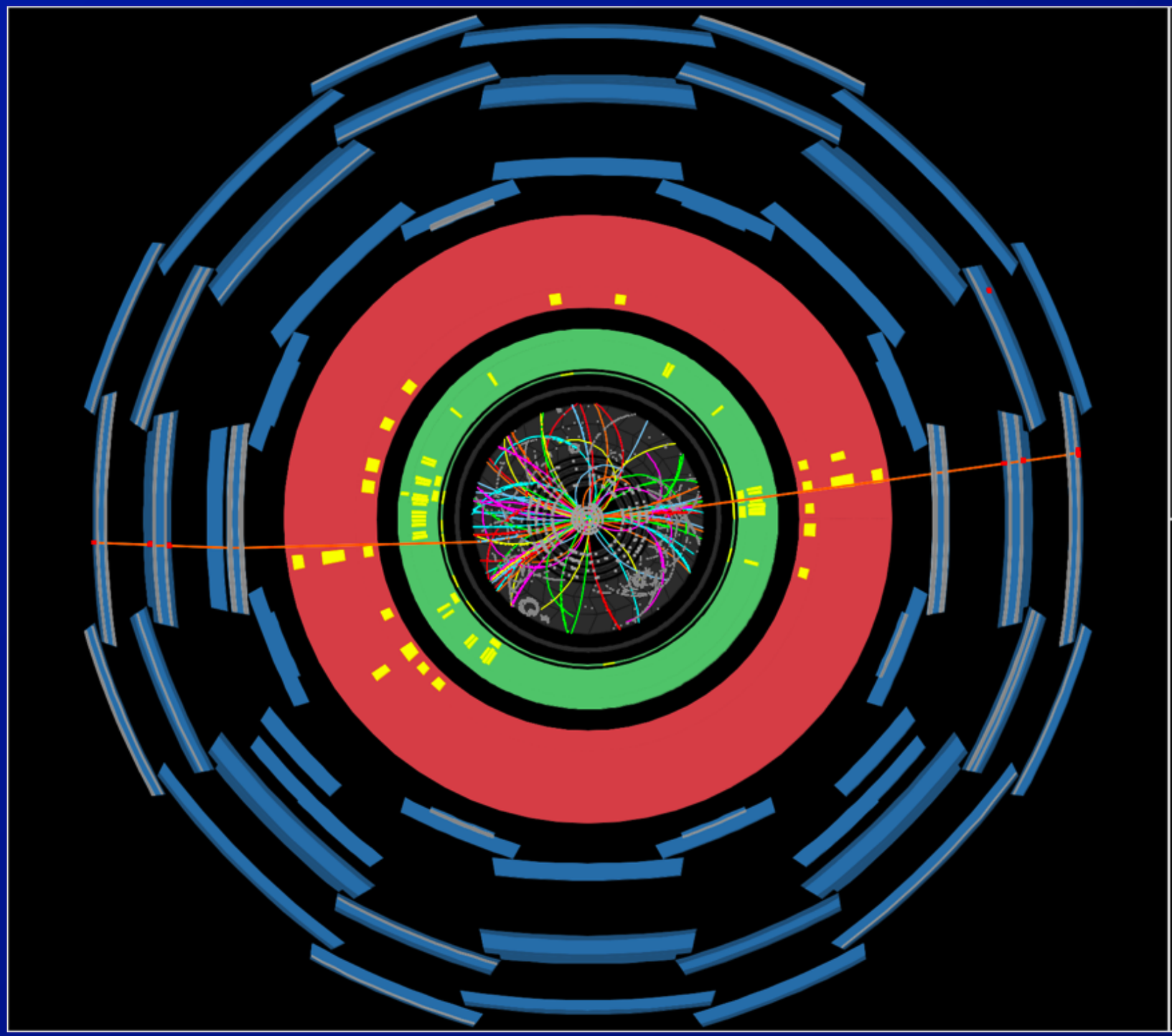
Bulk observables

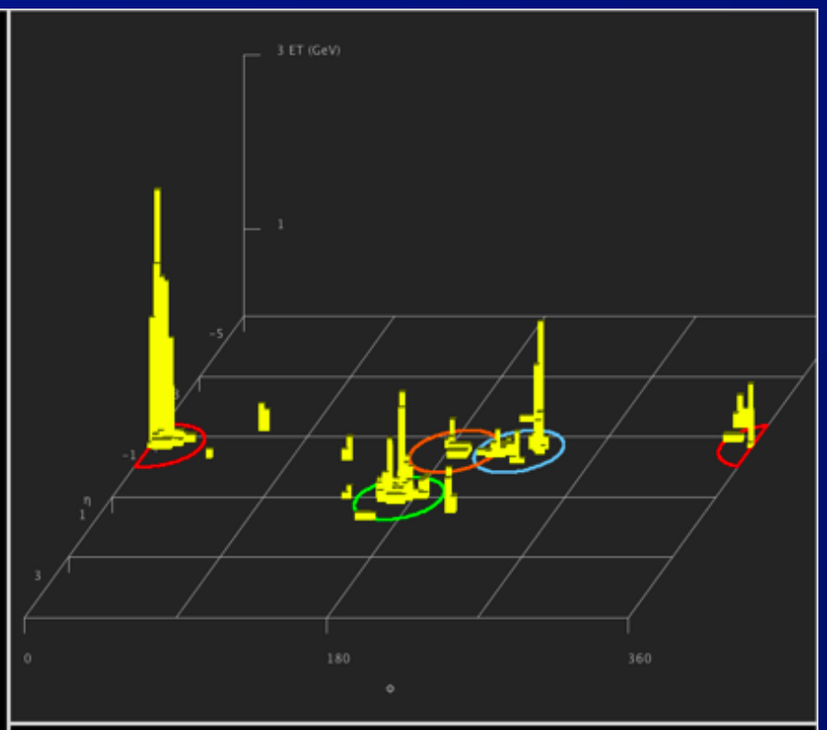
γ, π^0, isolated γ

Y, Y'

Jets

ATLAS Event Display





ATLAS EXPERIMENT

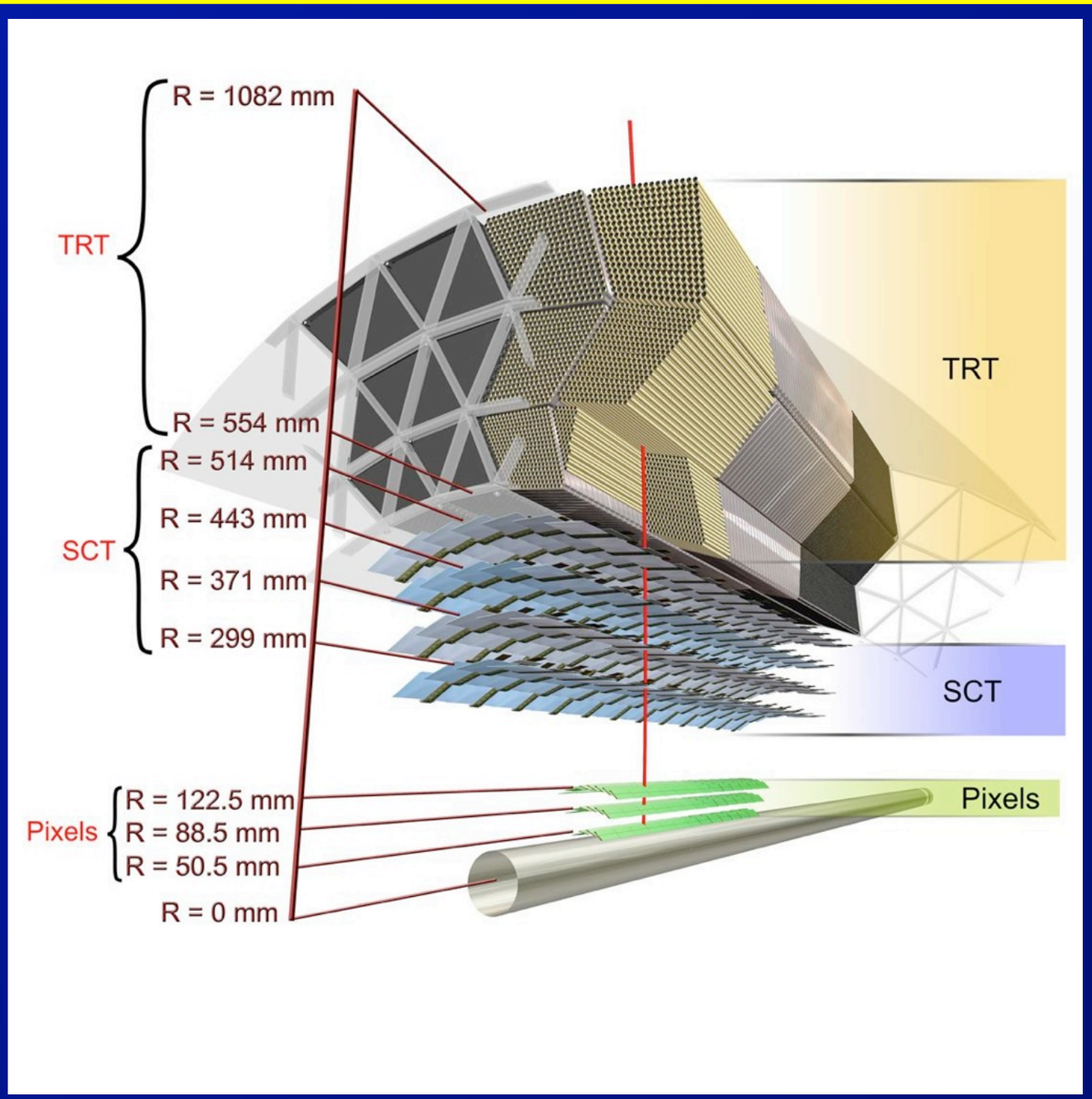
Run Number: 152166, Event Number: 890572

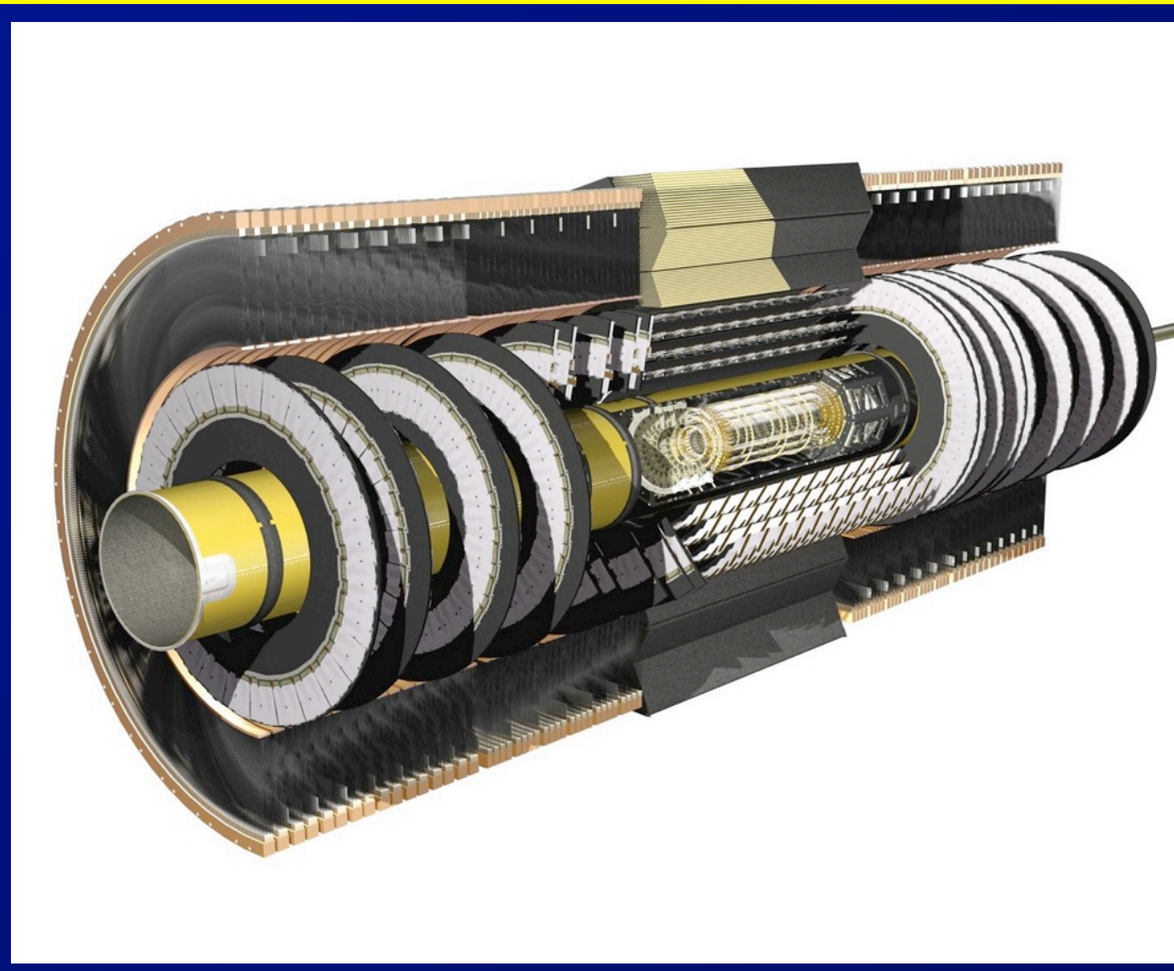
Date: 2010-03-30 15:19:40 CEST

7 TeV Event with Jets and 2 Muons

- Di-jet + two muons (heavy quark di-jet?)

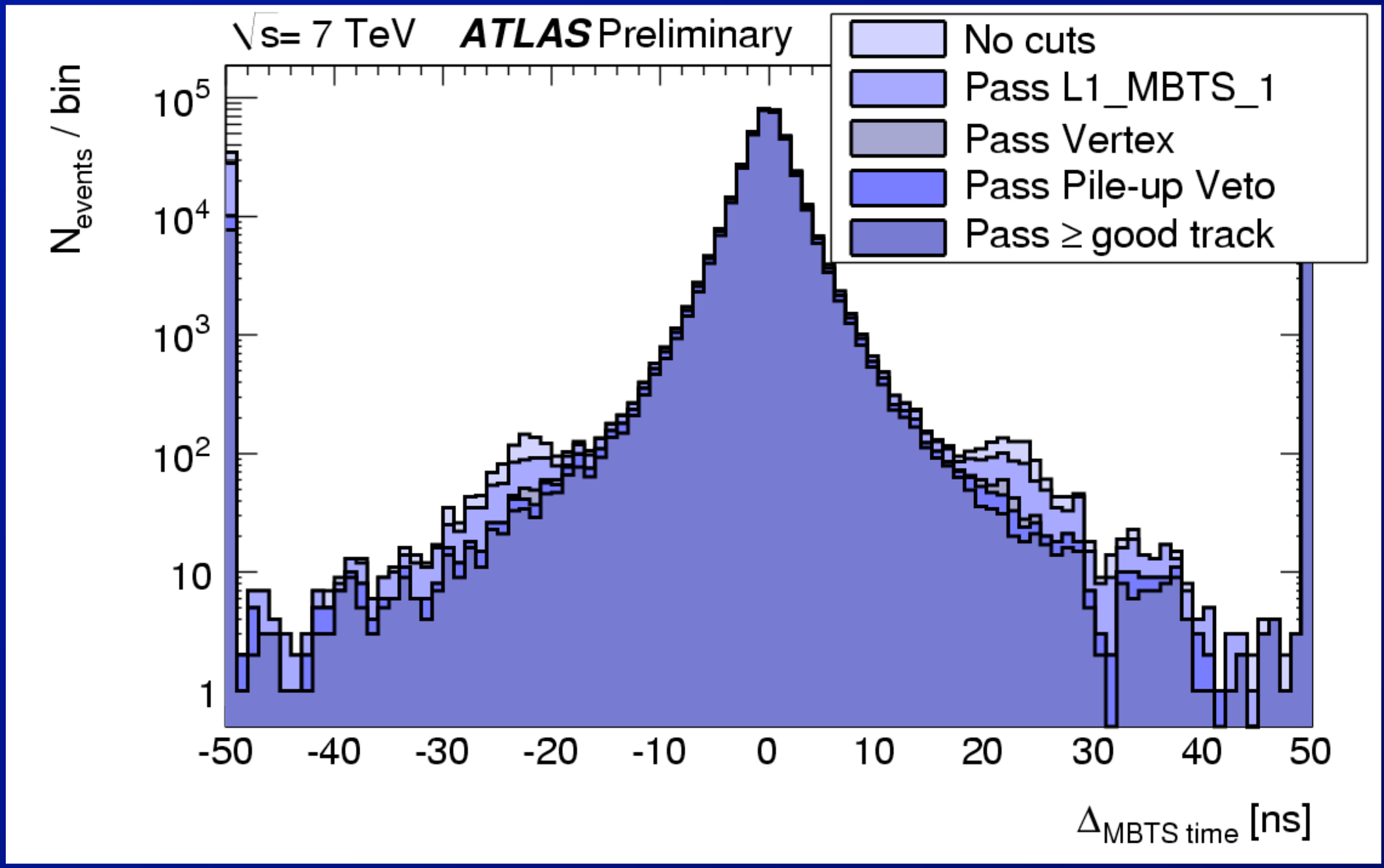
ATLAS Inner Tracker





- **Silicon detectors (only) used in "minimum-bias" results**
  - 3 pixel layers (50 x 400 µm)
  - 4 double-sided strip layers (80 µm x 12.6 cm, 2.3° stereo).

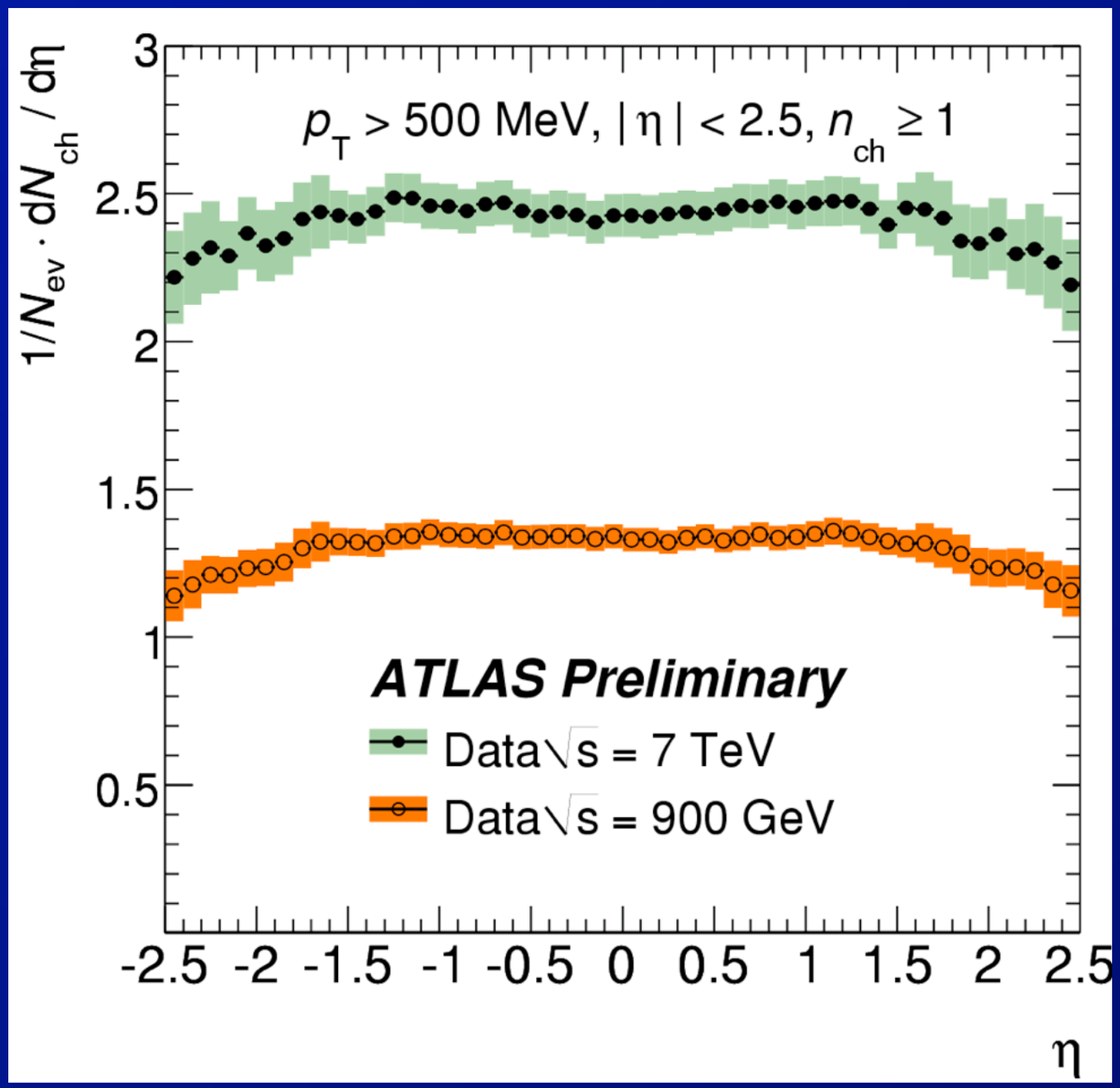
ATLAS p-p event selection

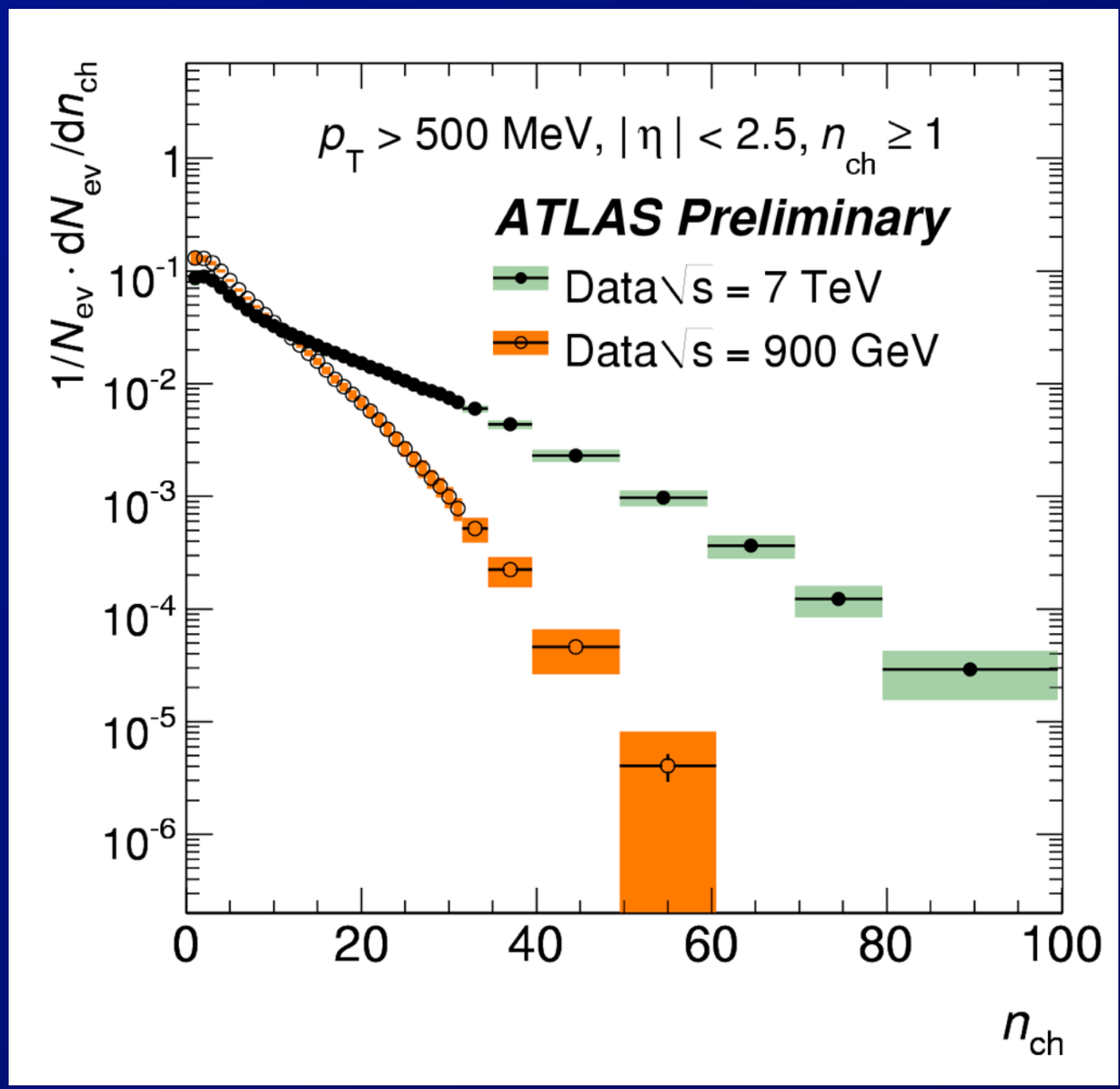


- **MBTS Time difference for different event selections**
  - Vertex requires 2 tracks w/ p_T > 150 MeV/c.
  - Good track has $|\eta| < 2.5$, p_T > 500 MeV/c.

p-p min-bias charged particle multiplicity

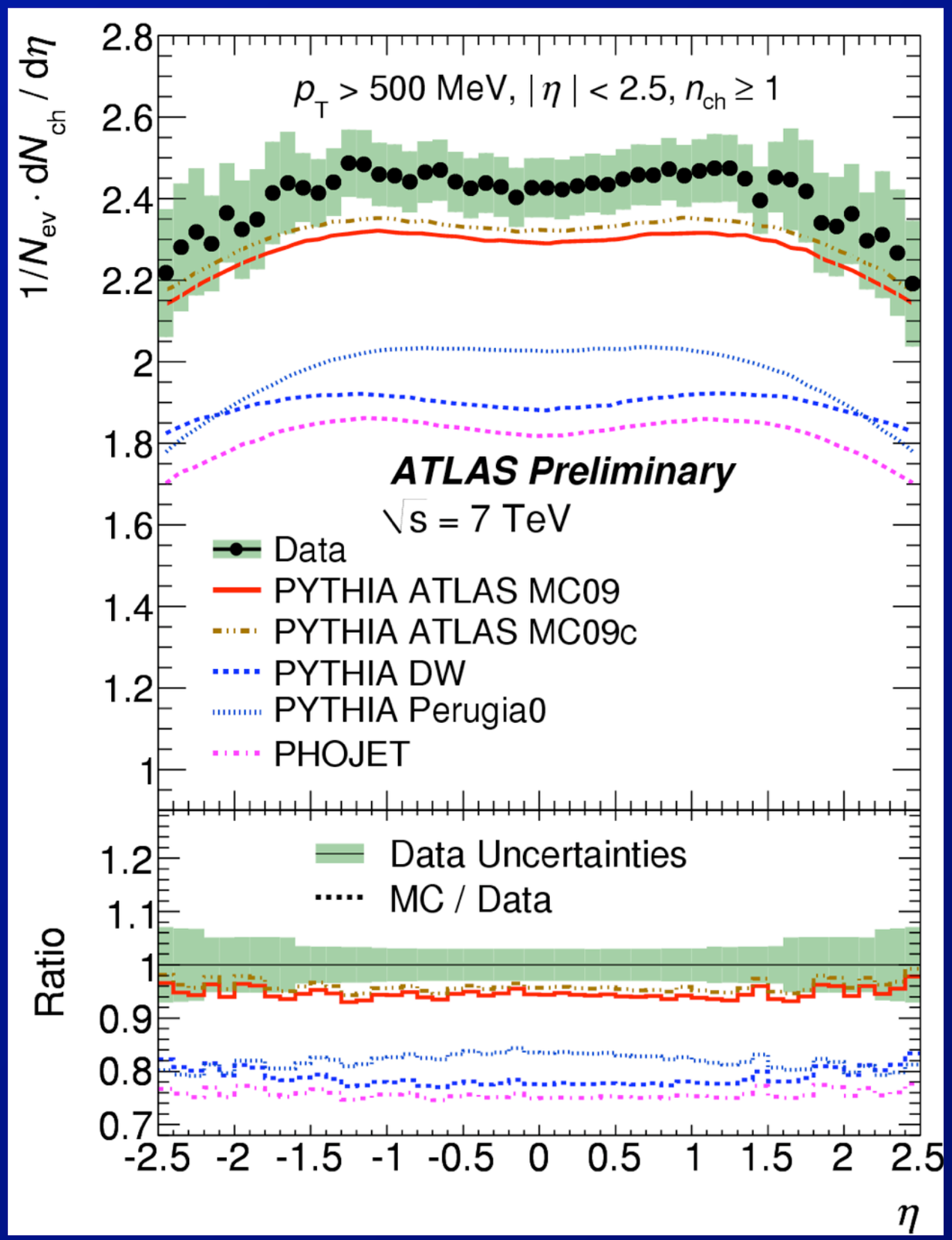
Analysis described in ATLAS-CONF-2010-024

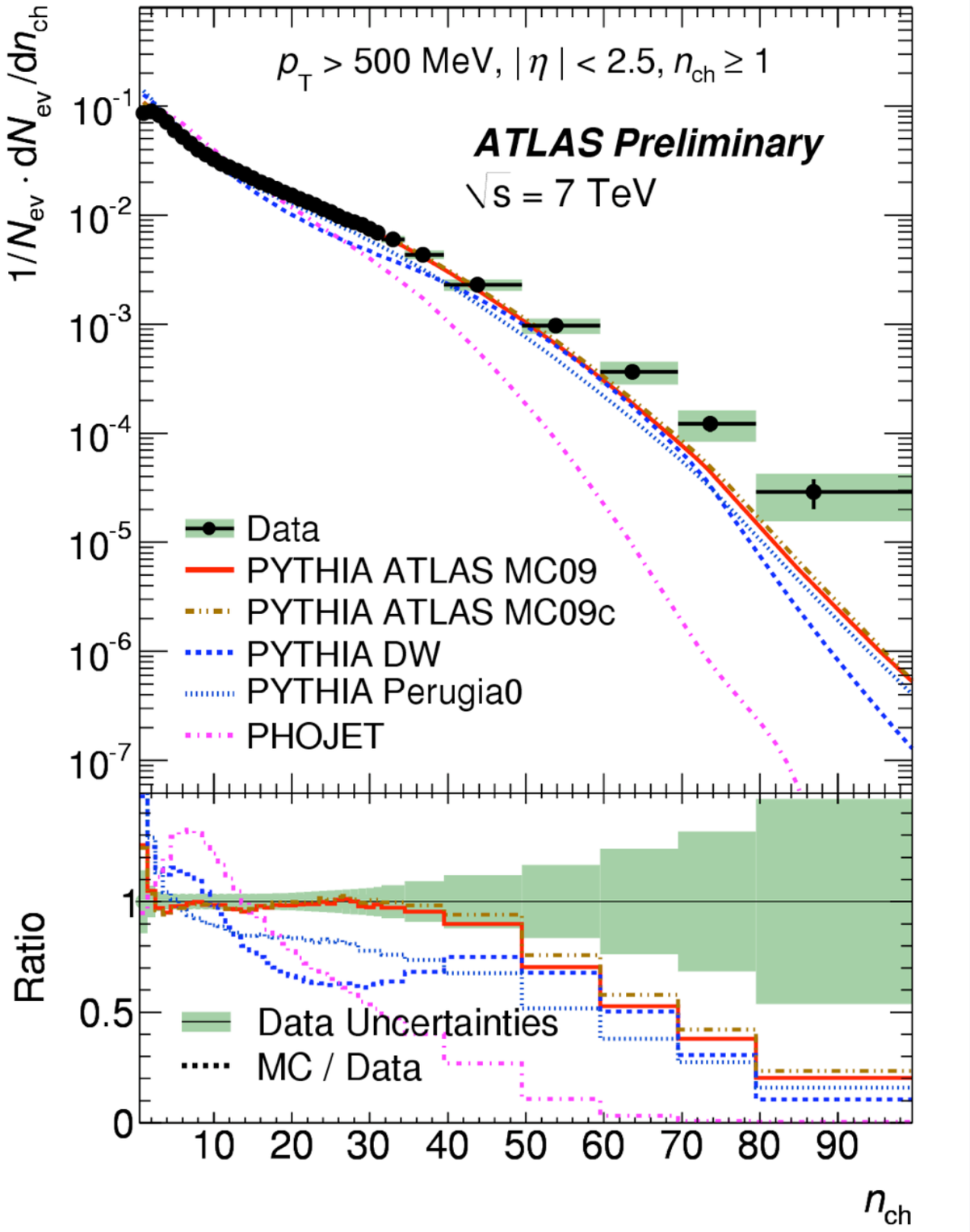




- **Event selection:**
  - Good vertex (2 tracks with p_T > 150 MeV)
  - At least one track with $|\eta|$ < 2.5 and p_T > 500 MeV

p-p min-bias multiplicity compared to PYTHIA

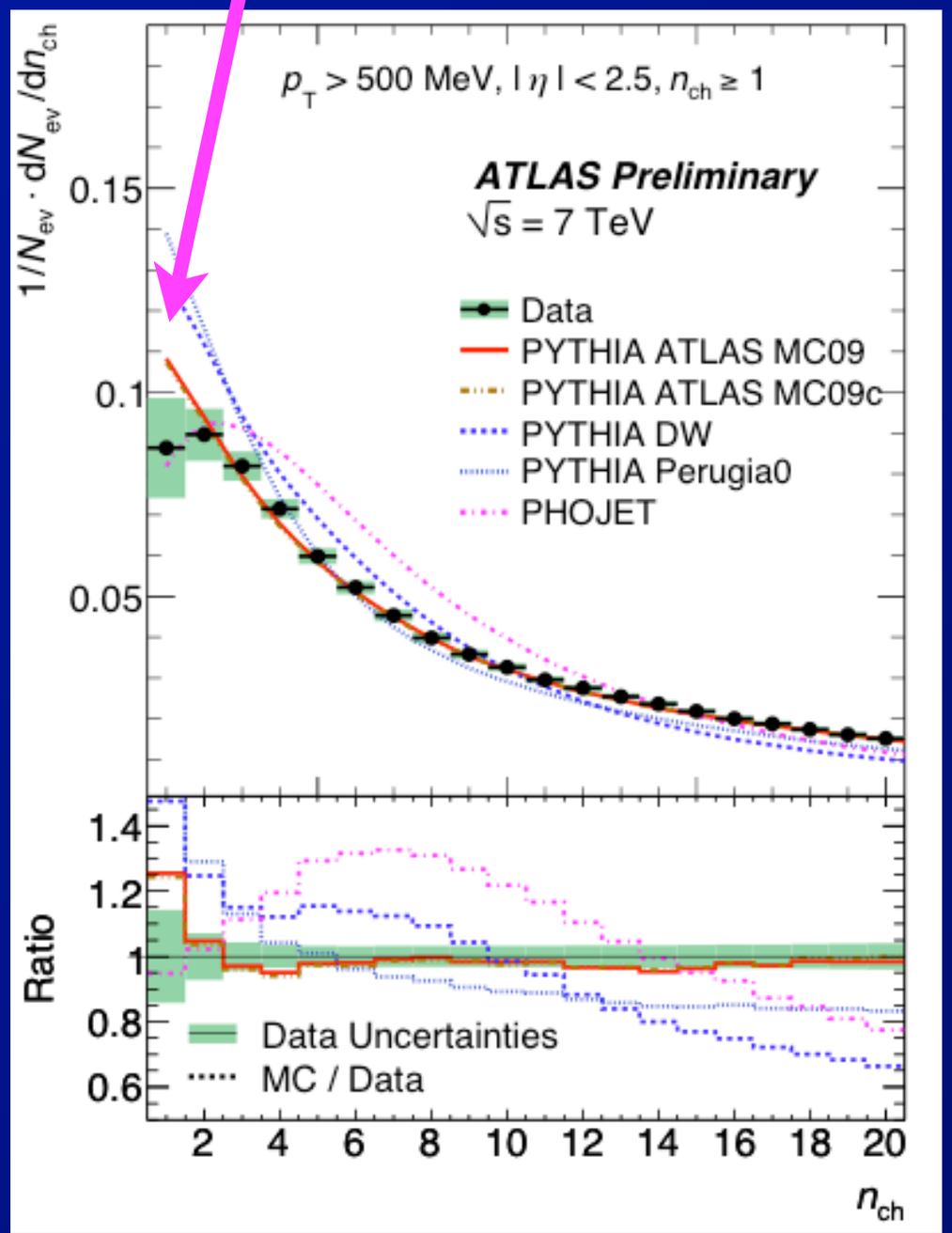


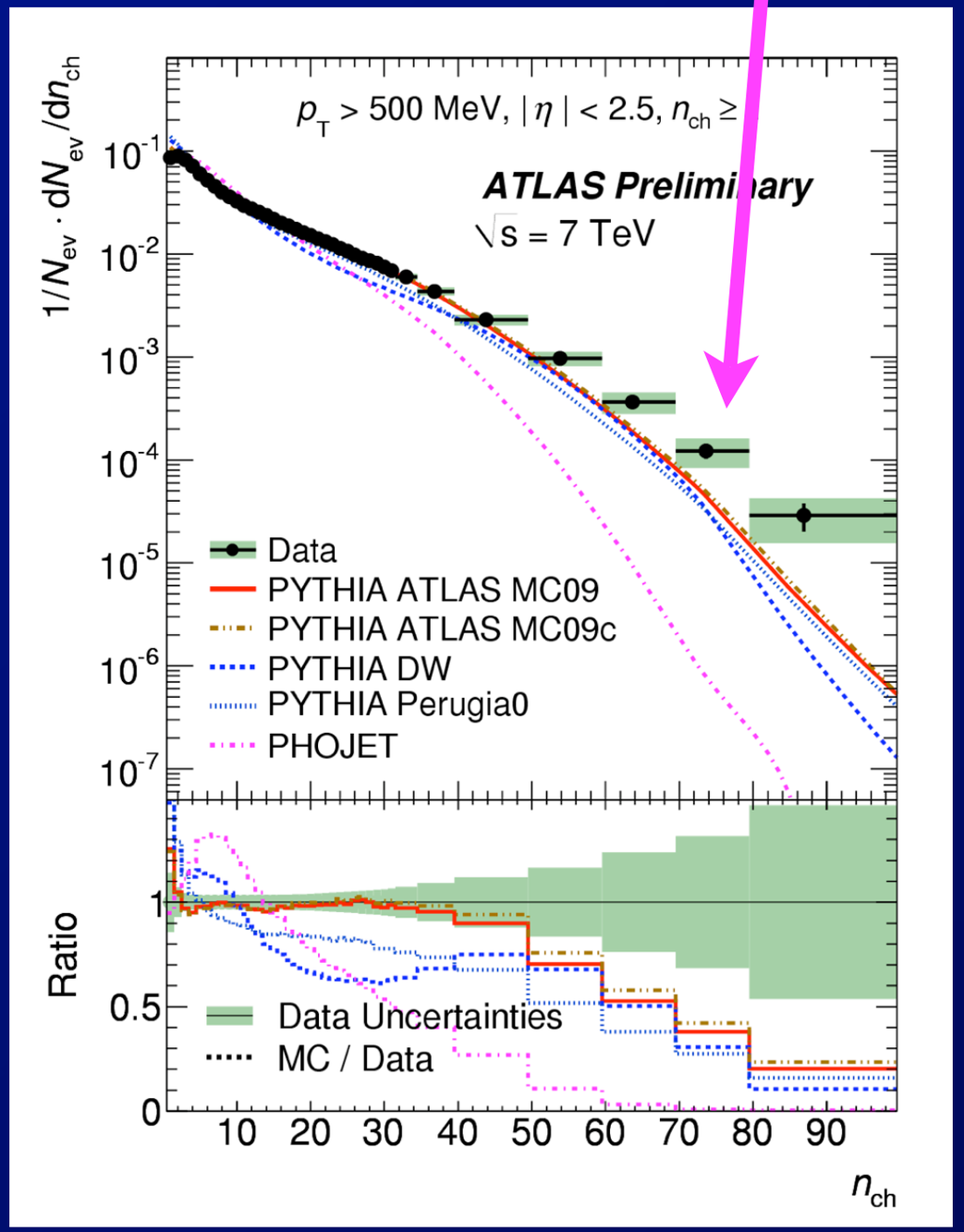


Min-bias multiplicity compared to PYTHIA (2)

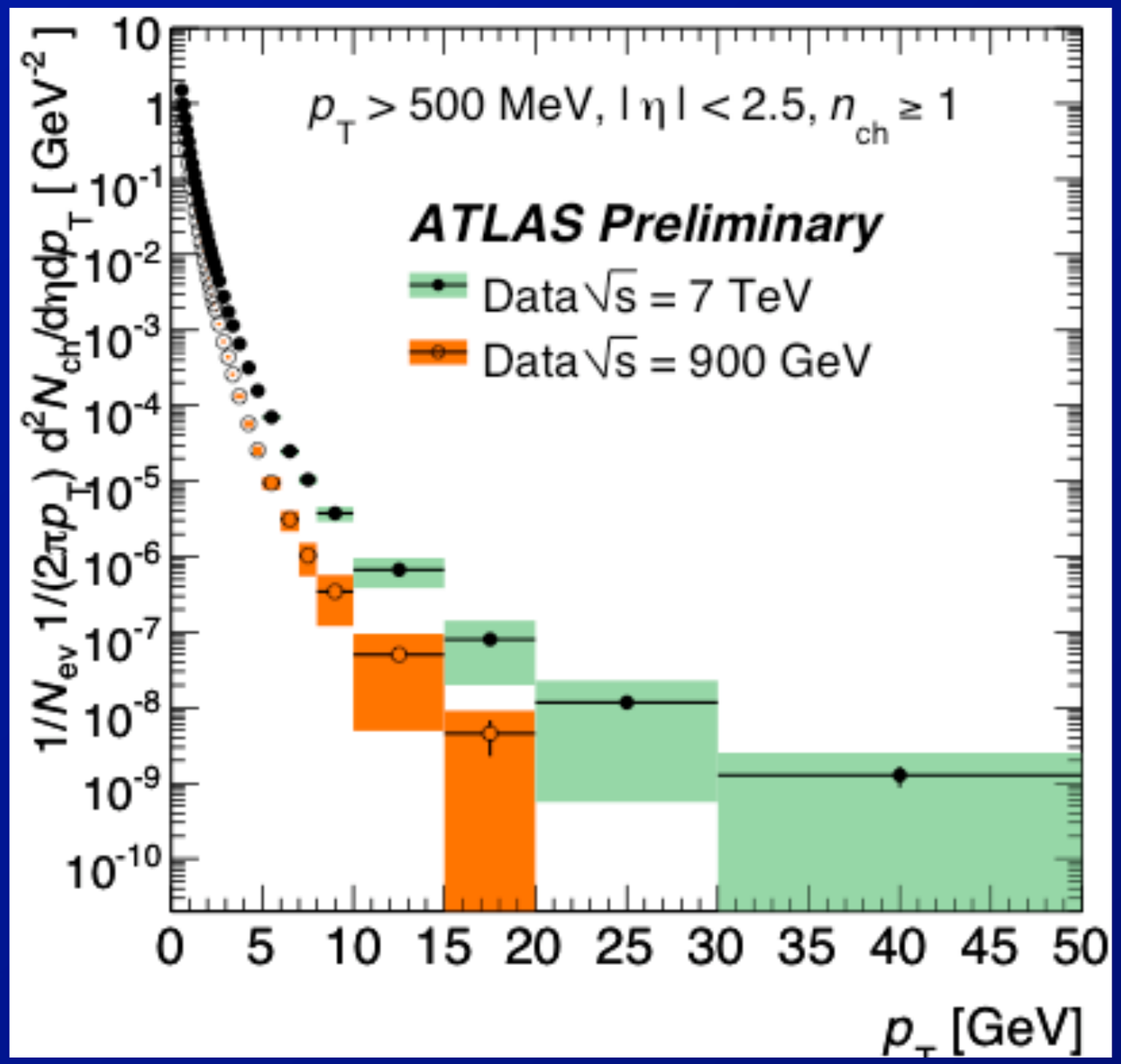
Some small difference at $n_{ch} = 1$

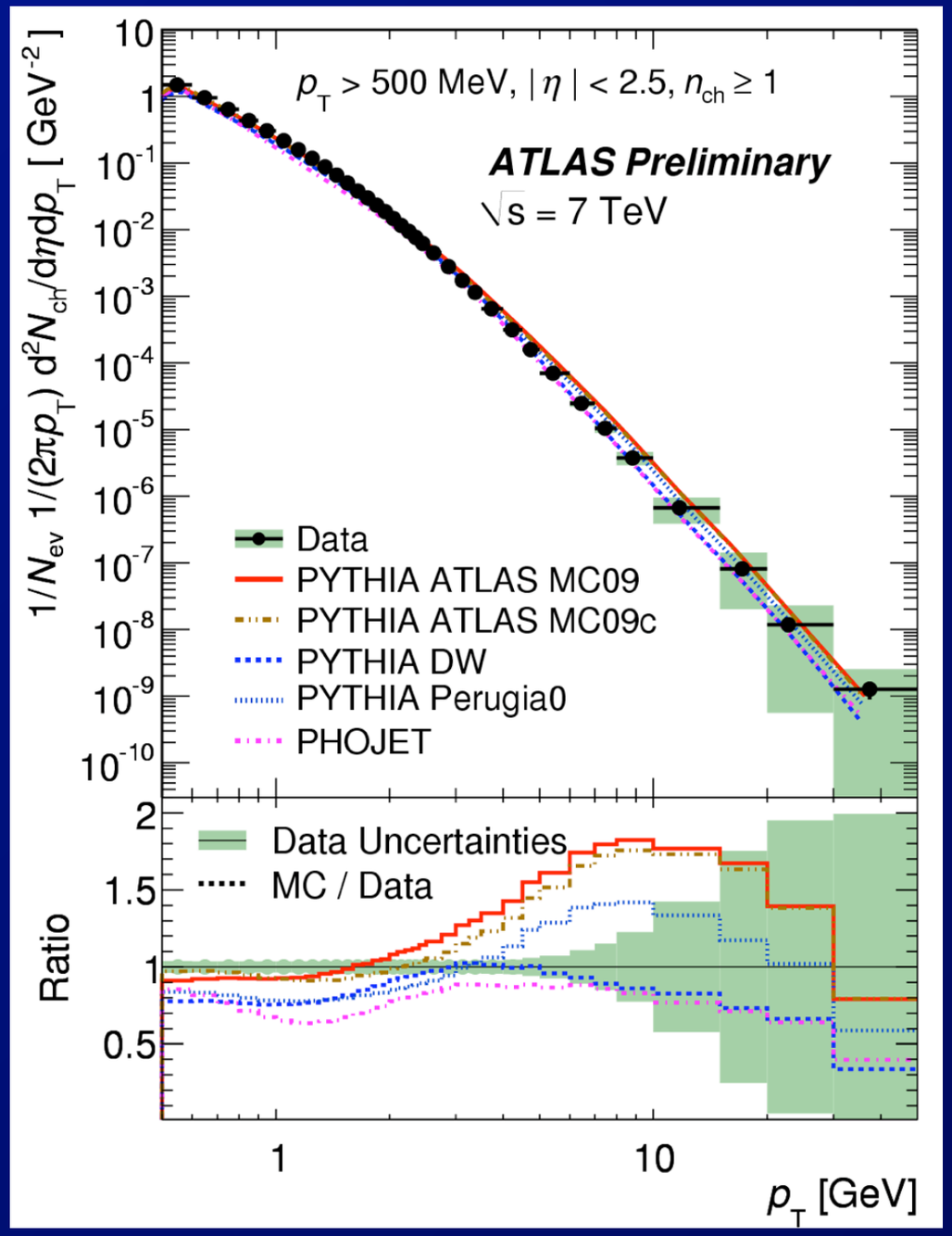
But more significant deviation at high multiplicity





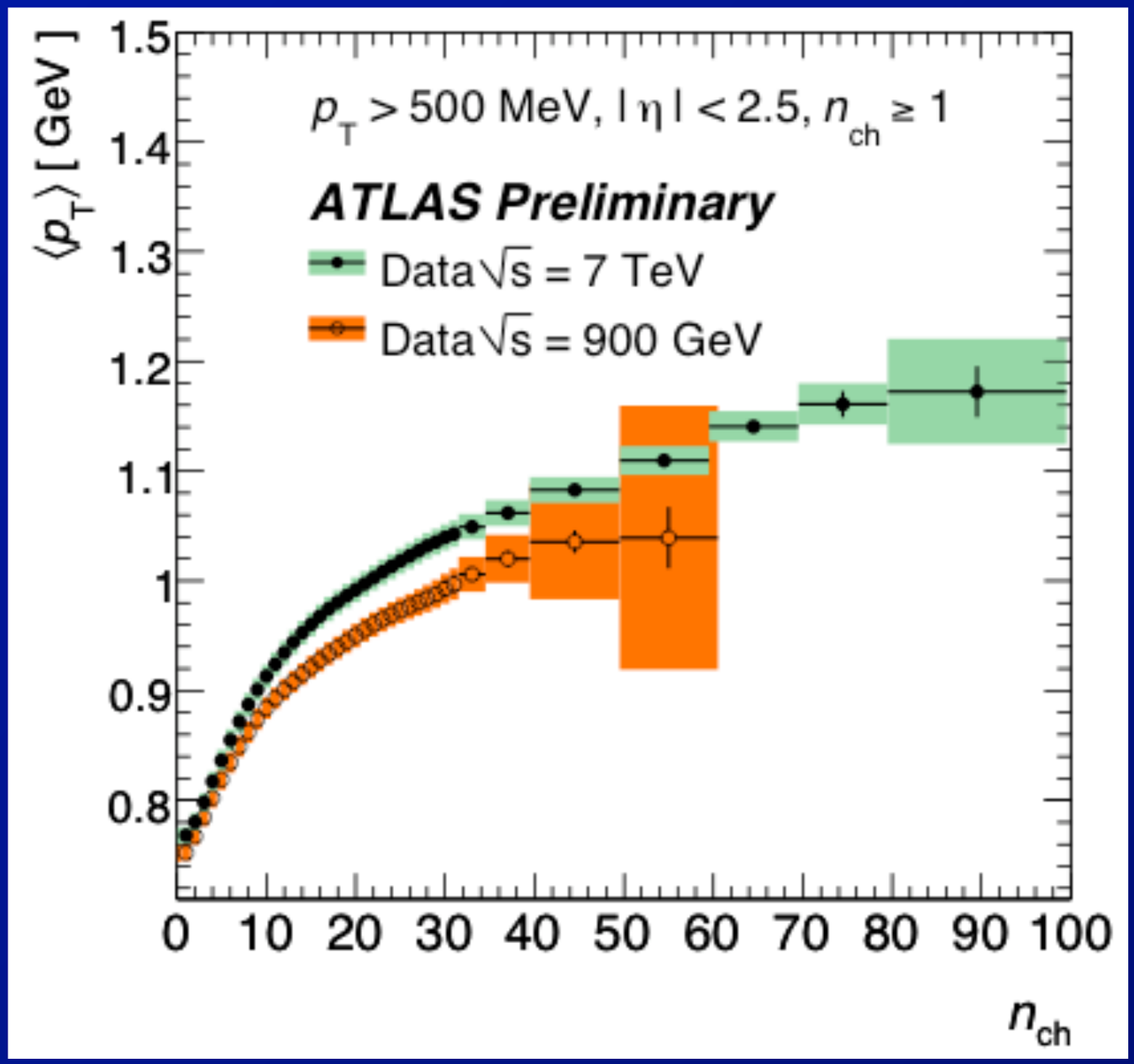
p-p min-bias p_T distribution

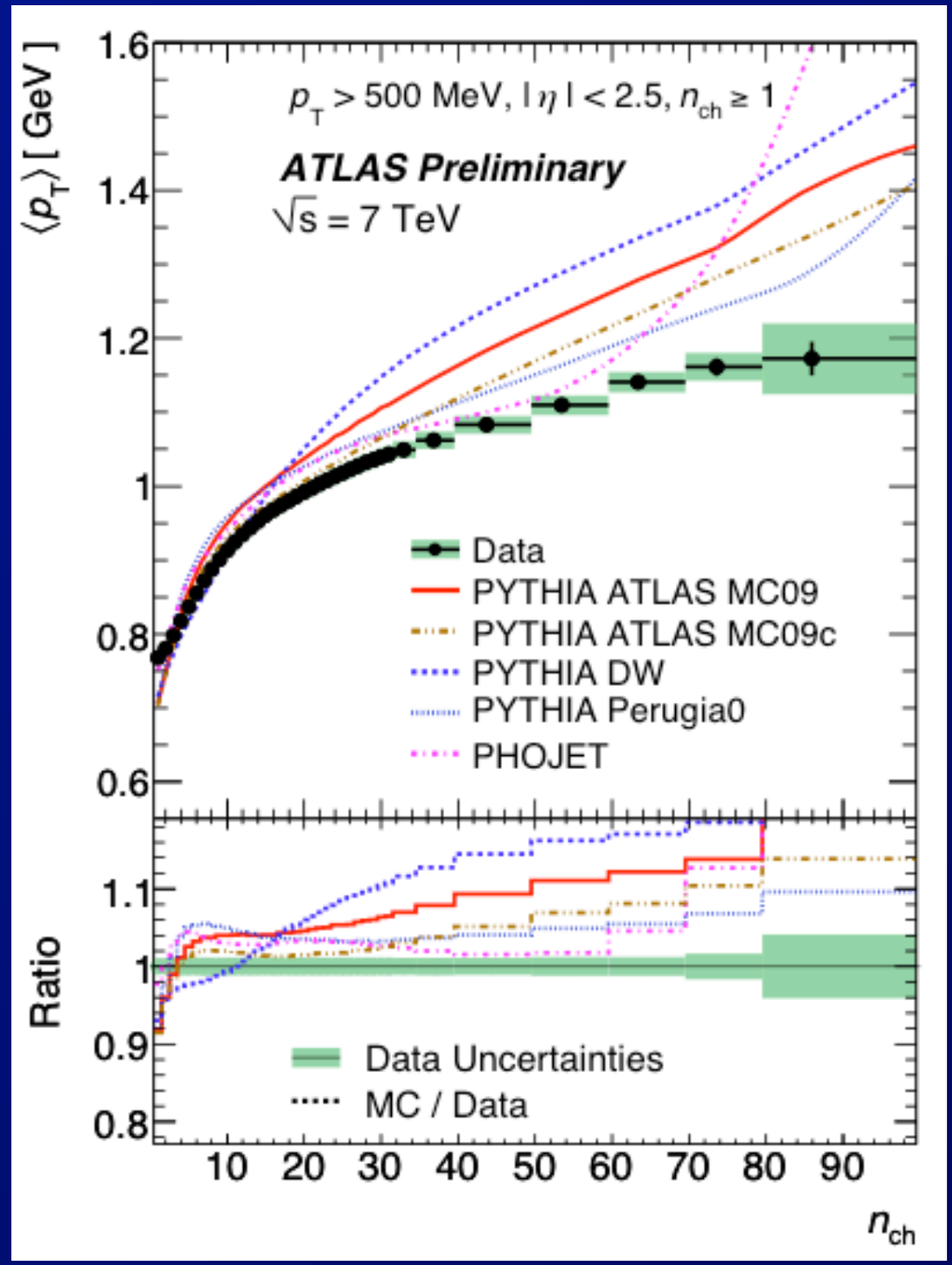




- PYTHIA parameterized using Tevatron data does well for $p_T < 2$ GeV/c, but significantly over-predicts for $2 < p_T < 10$ GeV/c

p-p min-bias <p_T> vs multiplicity

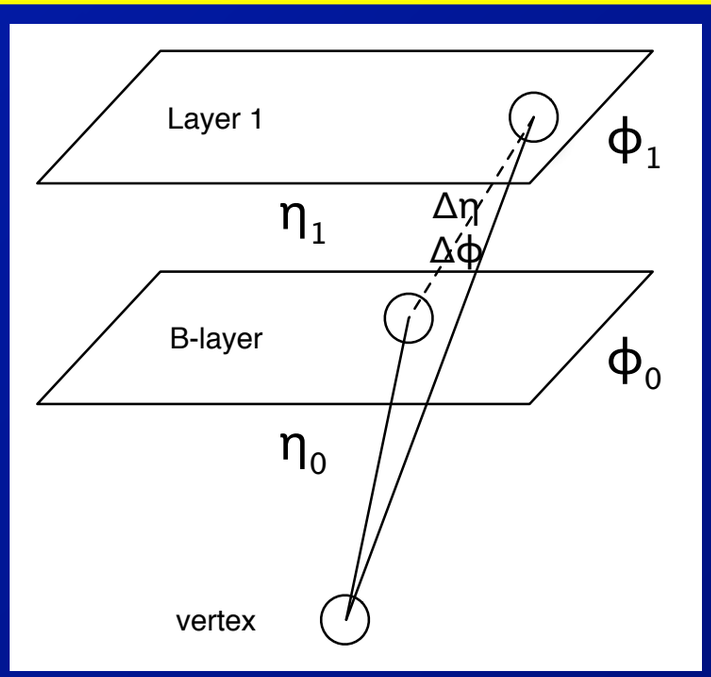




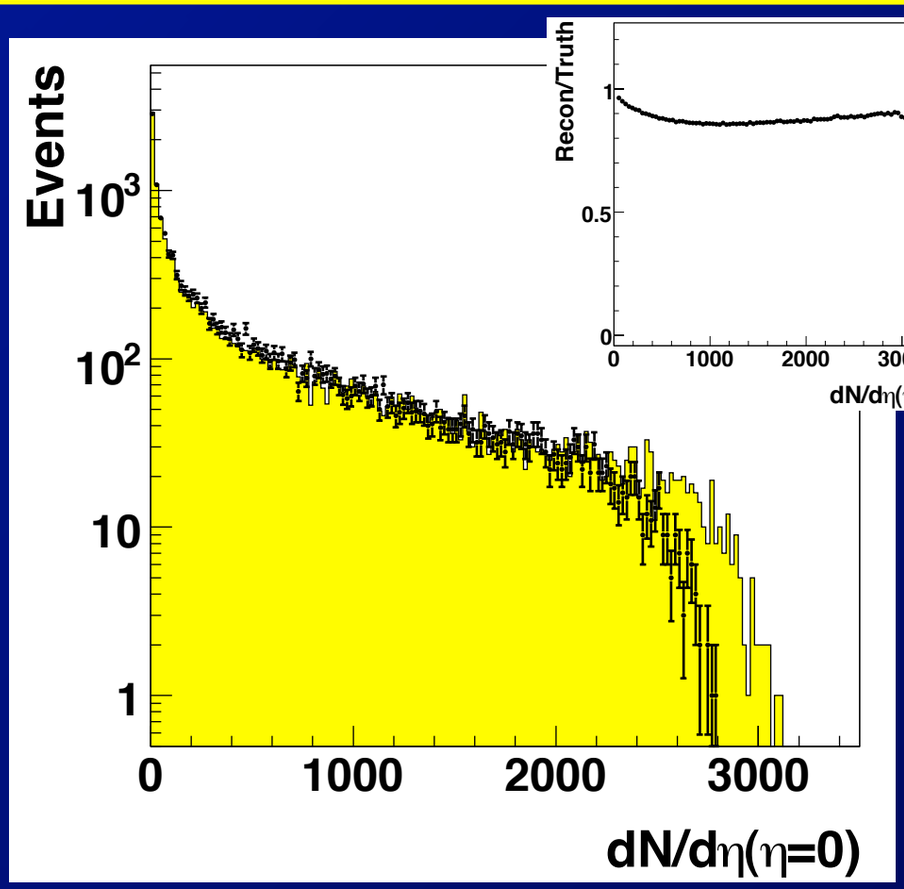
- PYTHIA (all tunes) badly over-estimates growth of <p_T> with charged particle multiplicity

Multiplicity, dN/dη measurement in Pb+Pb

Multiplicity, dN/dη Measurement in Pb+Pb



3-point tracks, including event vertex



- **Tracklets directly measure multiplicity, dN/dη**
  - Raw distribution (points) matches HIJING min-bias (hist)
  - Maximum 15% correction over entire centrality range.

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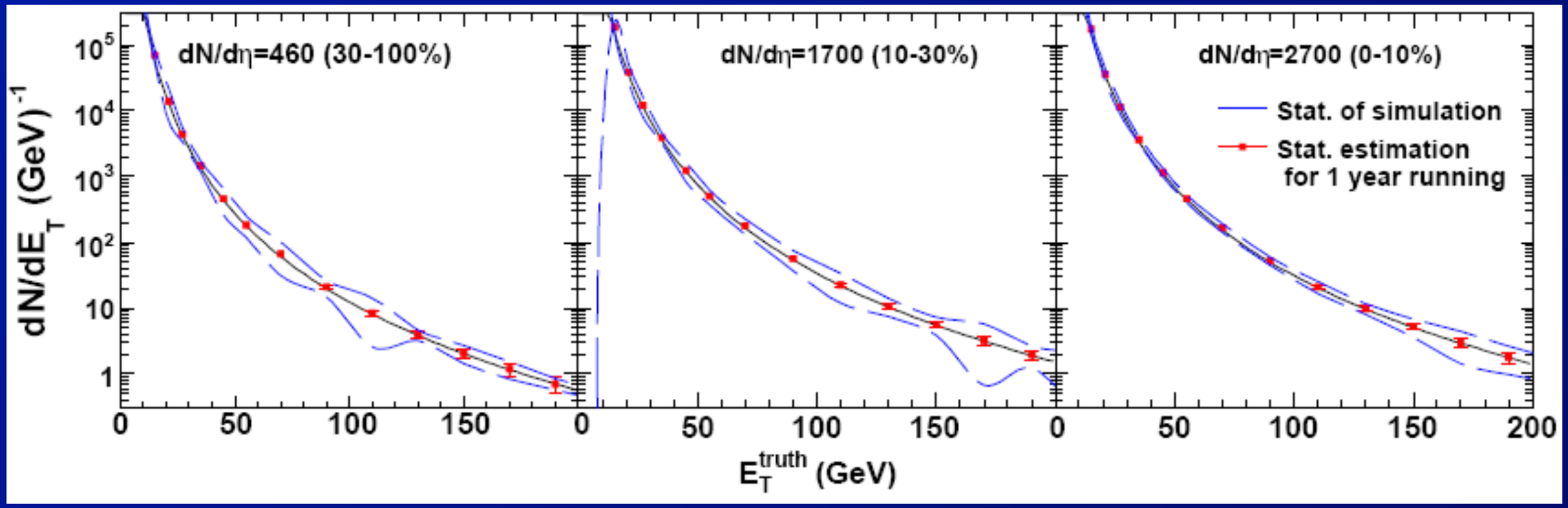
Old story

- **Tracklet method now being tested, calibrated on p-p data**
  - agrees with full tracking for p_T > 500 MeV to ~ 1%.

  ⇒ATLAS CONF note “soon”

Pb+Pb: Prompt Photon Spectra



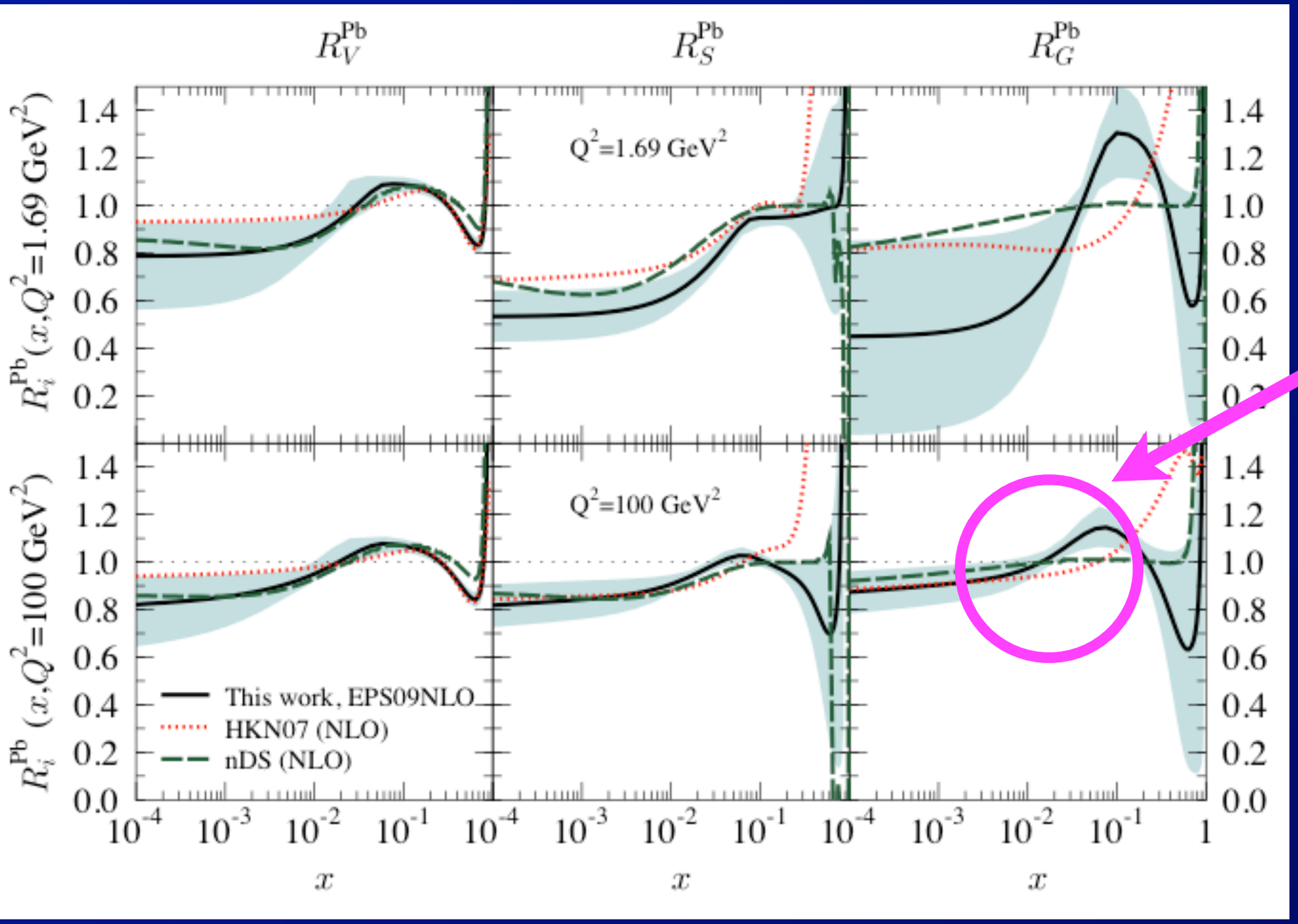
- **Demonstration of what measured prompt photon spectrum will look like for 0.5 nb^{-1} ($|\eta| < 2.4$)**
  - Background measurement & subtraction errors

    ⇒All for neutral hadron $R_{AA} = 1$ (worst case)
- **γ rates for (original) 1 year LHC run (0.5 nb^{-1}):**

  ⇒ 100k for $p_T^{\gamma} > 30$ GeV, 10k for $p_T^{\gamma} > 70$ GeV
- **How many runs will 0.5 nb^{-1} require?**

Nuclear PDFs, Impact on Pb+Pb Jets

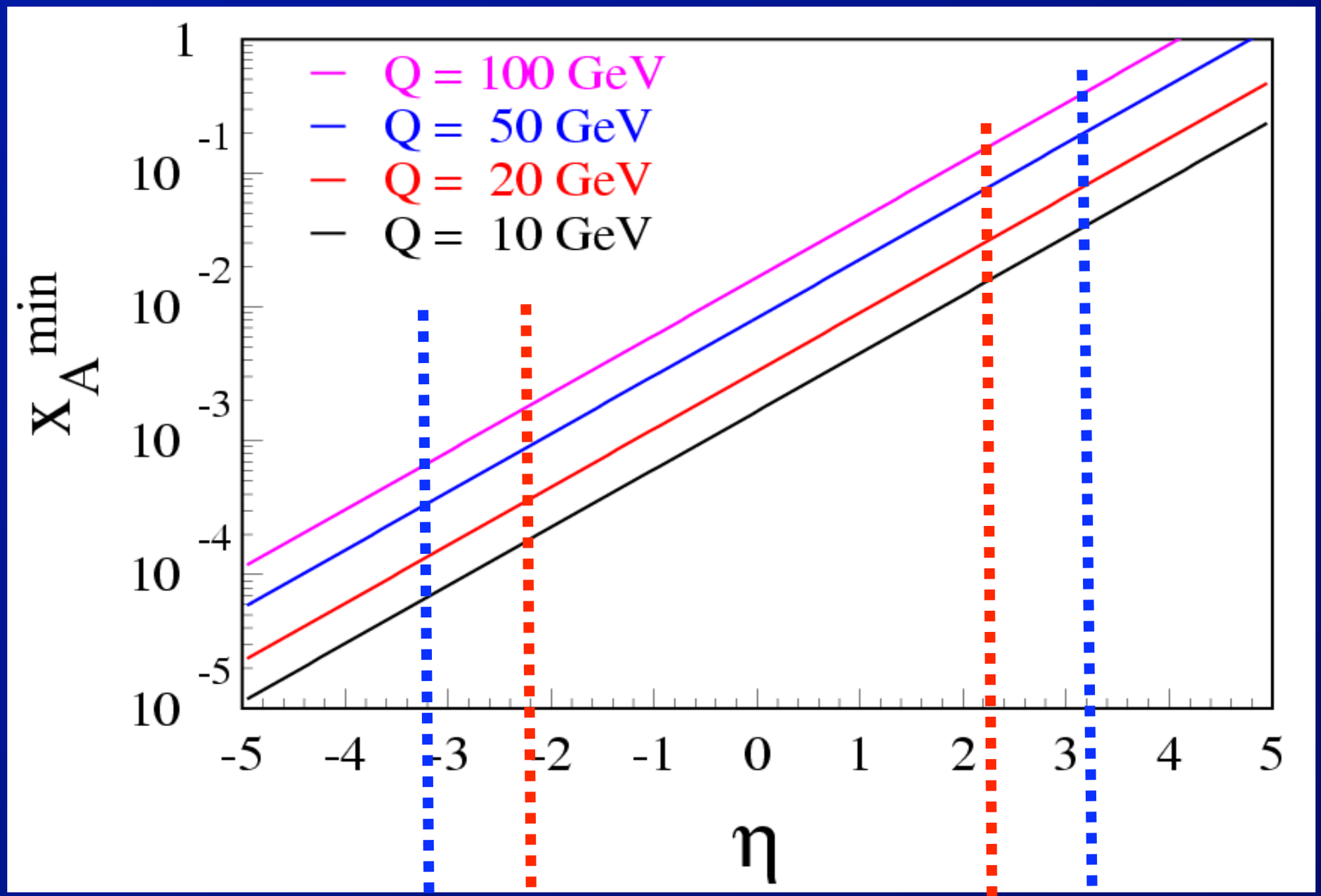
From EPS09, JHEP 0904:065, 2009



Region of x, Q^2 relevant for jets at mid-rapidity

- (Too?) small average modification of nuclear gluon distribution, but b dependence, y/η dependence?

ATLAS Acceptance, very rough x coverage



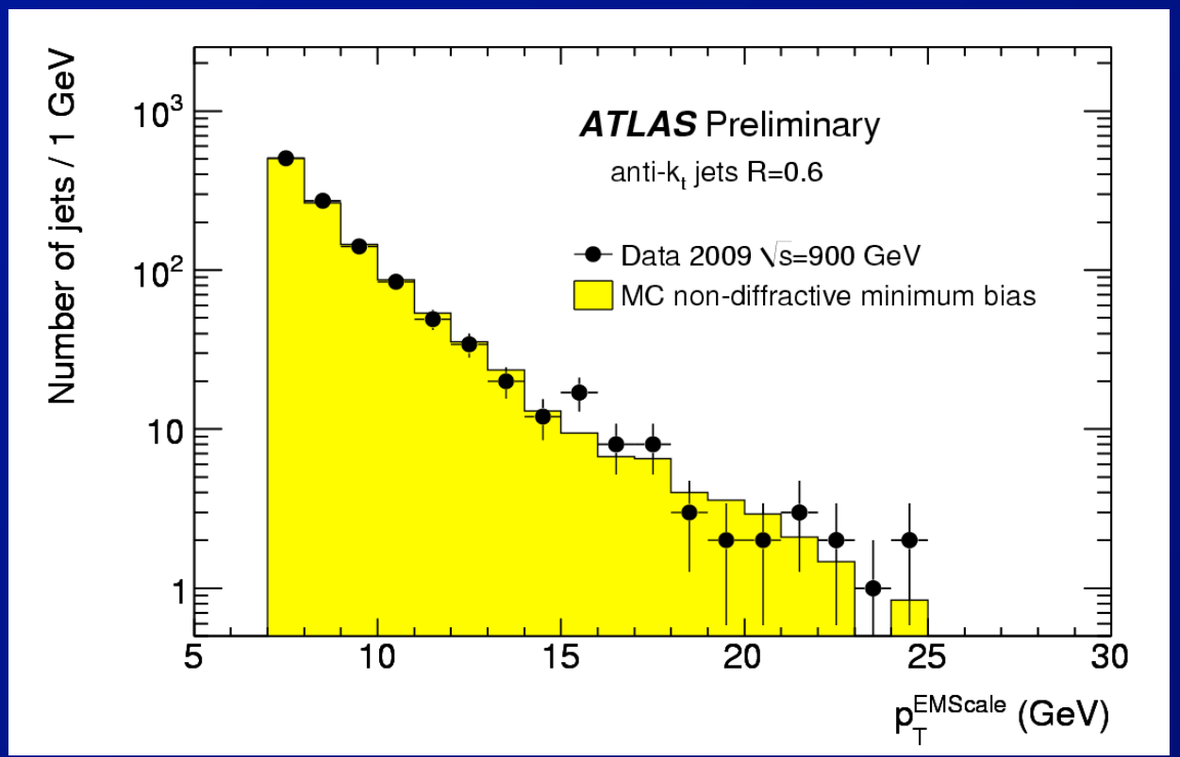
Naive 2→2 kinematics,

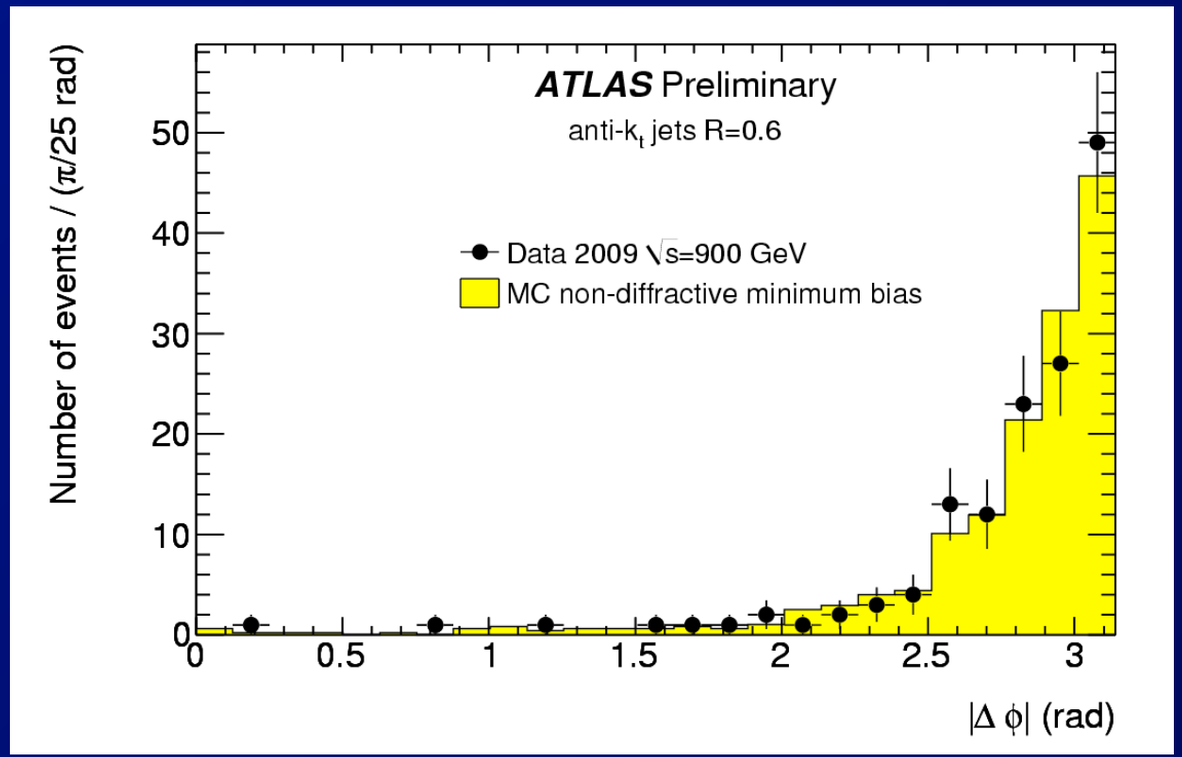
Does not account for p+Pb CM shift

Old - need to multiply all x_{min} values by 2

Jet Measurements @ Moderate p_T

- For jet measurements in p+p, p+Pb to be "interesting" need to keep Q^2 moderate
  - ⇒Need to measure jets down to ~ 10 GeV.
  - ⇒Done by ATLAS (and CMS) in 900 GeV p+p



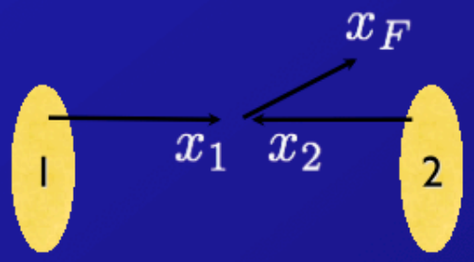


- A proof of principle -- many issues to get under control (underlying event, calorimeter noise)
  - ⇒Nonetheless, suggests Q^2 ~ 100 GeV^2 accessible.

Ultra-low x w/ ATLAS ZDC + precision EM

ATLAS: Low-x Physics w/ ZDC

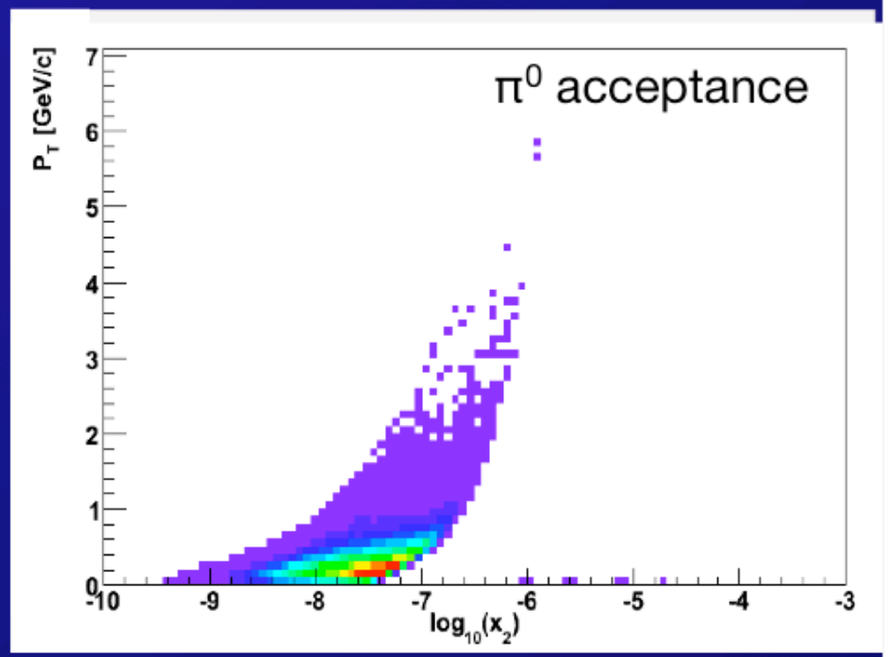
From P. Steinberg Quark Matter 2006 ATLAS heavy ion physics plenary talk



$$x_F = x_1 - x_2$$

$$x_1 x_2 = \frac{m_T^2}{s}$$

$$x_1 \sim \frac{m_T}{\sqrt{s}} e^{y} \quad x_2 \sim \frac{m_T}{\sqrt{s}} e^{-y}$$



- Can access x <~ 10^{-6} @ moderate pT (> 4 GeV/c)
  - Correlate with jets in ATLAS calorimeters ($|\eta| < 5$)
  - Study acoplanarity vs $\Delta\eta$

Extracted from a previous talk that was in turn extracted from a previous talk …

- I once made a rash statement: ATLAS ZDC w/ precision EM will provide lowest x for identified particles @ LHC
  - While it may have been rash, it was and still is true

ATLAS Low-x measurements

- **ATLAS will make a number of measurements that may provide insight on low-x physics**
  - Inclusive hadron production in p-p, Pb+Pb, p+Pb
  - Rapidity separated jets

    ⇒Too early yet for jets in range $3 < |\eta| < 5$ but will come
  - Diffractive jets

    ⇒Will calorimeter noise be low enough to allow clean identification of rapidity gaps?
  - Penetrating hard final states in Pb+Pb (e.g. direct γ)

    ⇒Potential probe of b dependence of shadowing

    ⇒But, "the devil is in the details …"
  - p+Pb a "playground for low-x physics in nuclei"

    ⇒An entire physics program in its own right

    ⇒p+Pb sooner than we once expected?